

Reflective cholesteric displays from conducting polymer substrates

W. Fritz, S. Smith, R. Hewitt, J. W. Doane

Liquid Crystal Institute
Kent State University
Kent, OH 44242

L. Huang, C. O'Ferrall, R. Shashidhar
Naval Research Laboratory
Washington D. C. 20375

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ABSTRACT

There is a great deal of interest in reflective cholesteric liquid crystal displays (Ch-LCDs) because they are lightweight, low power flat-panel displays. Furthermore, Ch-LCDs can be made bistable which allows for the manufacture of large area, high-resolution displays without the need for expensive, difficult to manufacture active matrix addressing schemes. Also, the bistability enables flicker-free operation. Currently, these displays are made using glass substrates. However, some applications require rugged (i.e., nonbreakable), flexible displays. The use of a plastic substrate would fulfill these requirements.

The transparent metal indium tin oxide (ITO) is currently used as the conducting electrode on glass as well as plastic substrates. While ITO works well with glass, it does not adhere as well to plastic, is brittle, and has a tendency to break under constant bend conditions. In this paper, we investigate substituting the more robust conducting polymer for ITO as the display electrode and determine the feasibility of producing a reflective Ch-LCD using plastic substrates with conducting polymer electrodes.

Keywords: reflective, cholesteric, liquid crystal display, plastic, conducting polymer

1. INTRODUCTION

Reflective Ch-LCDs are ideal for use in portable or handheld devices to display information such as maps, text or graphics because they offer high resolution, sunlight readable images on a lightweight, low-power display. These desirable optical properties are a result of the unique features of cholesteric liquid crystals.

When cholesteric liquid crystal material is confined between two closely spaced (on the order of 5 microns) substrates, it typically assumes the planar texture. In the planar texture, the liquid crystal director (the average orientation the liquid crystal molecules point at that region in space) rotates about an axis. For the perfect planar texture, all axes are oriented perpendicular to the substrates. The twisting of the liquid crystal director about these axes creates a continuously varying, but periodic dielectric permittivity. Because of this periodicity, the material will Bragg reflect light incident on the sample when the pitch (distance over which the director rotates 360 degrees) is comparable to the wavelength of incident light. Furthermore, cholesteric liquid crystals possess the unique optical feature of decomposing white light into its left- and right-hand circular components by Bragg reflecting one component and transmitting the other. The wavelength of the reflected component is given by the Bragg formula, $\lambda = np$, where n is the average refractive index and p is the pitch length of the cholesteric helix. There is also a band of wavelengths (on the order of 100 nm) reflected about the center Bragg wavelength given by $\delta\lambda = \lambda\delta n/n$, where δn is the birefringence of the material. This selective reflection of light produces color without the use of expensive, difficult to manufacture and intensity reducing color filters. Different colors can be reflected by merely changing the chemical composition of the liquid crystal mixture, which changes the pitch and thus the center Bragg reflected wavelength.

By applying an electric field to the cholesteric liquid crystal mixture, the material can be placed in the focal conic texture. In this state, the helical axes are oriented in random directions. The material ceases to reflect light and becomes transparent or

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weakly scattering depending on the material composition. By treating the bottom substrate with a black absorber, a pixel in the focal conic state appears black.

Cholesteric materials were recognized as possible materials to be used for imaging in the late 1960s and early 1970s^{1,2,3}, but it was not until the early 1990s that researchers at the Liquid Crystal Institute at Kent State University further developed the materials and techniques for reflective displays⁴. They found that by introducing a specially prepared polymer network or with suitable treatment of the substrate surface, they could render the display spatially uniform, decrease color change with angle, and increase the contrast ratio^{5,6}. Furthermore, these techniques stabilized the focal conic texture and thus made the display bistable⁷.

Utilizing these developments, reflective Ch-LCDs have been made using glass substrates coated with the transparent metal ITO to apply an electric field to the material. However for many applications, there is a need for non-breakable (rugged) and flexible displays. For these applications, the use of glass substrates is not acceptable.

An alternate approach is to use plastic substrates. But, the use of plastic substrates for liquid crystal displays has had little development. Ch-LCD technology is more forgiving in the use of plastic substrates than other LCD technologies. Unlike TN, STN, or FLC LCD technologies, optically birefringent plastic can be used, opening up a broad variety of plastic materials. Also, the use of plastic requires low processing temperatures, which makes using plastic for active matrix technologies extremely difficult. However, because of the bistable operation of Ch-LCD technology, an active matrix is not required for a large area, high resolution display.

For any display technology regardless of the substrate, some type of electrical connection between the drive electronics and the display is required. Typically, in those efforts where plastic substrates are used, the approach is to coat ITO on the substrate rendering it electrically conducting. However, while improvements are in progress, the ITO currently coated on plastic does not adhere well, is brittle, and has a tendency to crack, particularly under constant bend conditions.

Work at the Naval Research Laboratory (NRL) and other laboratories has led to the potential use of conducting polymers as electrodes⁸. Certain conducting polymers have an electrical resistance comparable to ITO, while maintaining similar optical properties, in particular high transparency. These conducting polymers adhere well to plastic, are not brittle, and do not break under constant bend conditions. Also, while patterning of ITO to form the multiplexed display electrodes requires complicated lithography and etching, conducting polymers have the potential for printing, thus greatly improving the manufacturability of plastic LCDs.

The following discusses the results from using conducting polymer electrodes on plastic substrates to produce a reflective Ch-LCD.

2. EXPERIMENT

We used the conducting polymer polypyrrole for the display electrodes. The material was deposited on 7mil plastic poly(ethylene terephthalate) denoted as PET. Lithography and etching techniques were used to pattern the conducting polymer to a resolution of 80 lines per inch (lpi). In addition, a 400 angstrom SiO_2 layer was deposited by low temperature electron beam deposition to serve as an insulator to prevent electrical shorting between the top and bottom substrates and to act as an alignment layer.

The top (transparent) substrate had a thin polypyrrole layer deposited to achieve a nominal 75% transmission. The bottom substrate had a thick layer deposited to provide both the electrode and to act as a black absorber. As discussed, the dark state is created by coating a black absorber on the bottom substrate. Because most black absorbers are nonconductive, they are coated on the outer side of the bottom substrate. However, the dark state becomes even darker when the black absorber is placed closer to the liquid crystal material because of the reduced scattering this creates. While placing a nonconductive black absorber on the inside of the bottom substrate makes the dark state darker and thus improves the contrast ratio, it also increases the inner thickness of the pixel which increases the drive voltage to unacceptable levels.

Established fabrication steps used for glass substrates were transferred to processing with plastic. Modifications to processing were developed due to the unique properties of plastic such as using solvents that did not attack the plastic, using lower processing temperatures than that used for glass, developing special handling procedures due to the flexibility of plastic, and implementing techniques to remove trapped elements in the plastic substrates.

We used the vacuum fill approach to fabricate the display. In this method, a display has two substrates attached with an epoxy seal around the periphery of the display and are separated by 5 micron plastic spacers. The display is evacuated and a nematic/cholesteric liquid crystal mixture is injected in the display through a small fill opening in the seal by external atmospheric pressure.

One drive electronic approach to address a Ch-LCD is to use a sequential row address scheme, where a row is selected with a single, narrow high voltage pulse, and data placed on the column drivers. We fabricated single pixel samples to measure the electro-optic characteristics. The measurements revealed similar results as those found for devices fabricated with glass/ITO substrates ensuring the compatibility of plastic/conducting polymer devices with this drive electronics approach.

To make connections between the drive electronics and the conducting polymer electrodes, we used ELFORM TAB cable. This material consists of electrically conducting lines printed to a resolution of 80 lpi on a graphite particle/polymer resin matrix deposited on a PET substrate. We developed appropriate time, temperature and pressure bonding parameters to achieve a bond with good electrical and mechanical integrity.

3. RESULTS

Figure 1 shows a completed 2"x2", 80 lpi display. Numerous images were addressed on the display from either the internal memory of the drive electronics or externally from a computer. As shown by Fig. 1, the conducting polymer electrodes can be used as a substitute for ITO to apply an electric field to address an image on the Ch-LCD.

The black lines on the display are the result of electrical shorting. Failure analysis showed the shorting was primarily due to anomalies in the conducting polymer formed during the deposition process. Subsequent processing changes resulted in the amelioration of this failure mechanism. It was also determined that the e-beam SiO_2 layer was not providing good insulation due to the penetration of a substantial portion of the layer into the soft conducting polymer during the deposition process. Investigation of other insulating materials is in progress.

Nonuniformities and voiding across the display occurred in the early prototypes such as the one shown in Fig. 1. Subsequent improvements in substrate pre-processing and various fabrication steps indicate high-quality Ch-LCDs can be manufactured with appropriate techniques.

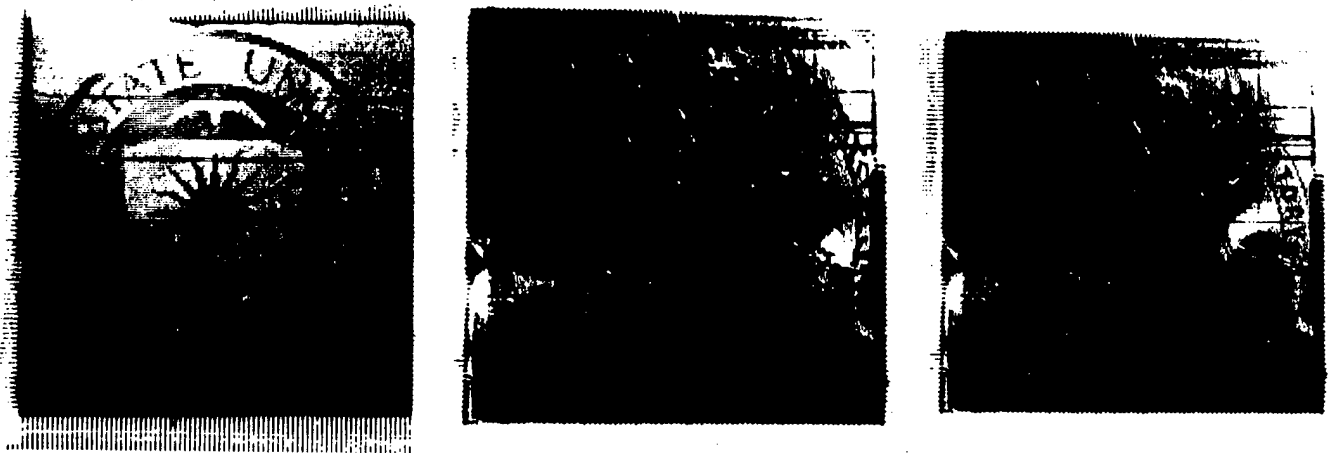


Fig. 1. Reflective Ch-LCD made with plastic substrates with conducting polymer electrodes.

4. CONCLUSIONS

We have successfully demonstrated a working reflective Ch-LCD made with plastic substrates using conducting polymer electrodes. The use of plastic substrates for LCDs opens up large new areas of applications. By using plastic, the displays are lighter in weight than their glass counterparts and they are much more rugged (nonbreakable). The displays with plastic can also be made flexible enabling their use for novel applications such as body-mounted displays. The use of conducting polymer provides a more robust, reliable electrode material than ITO on plastic, in addition to potentially being more amenable to low cost, high volume production.

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